How to Improve Power Factor, Voltage Regulation and to Reduce Harmonic Distortion of an Industrial Plant, using a Power System Simulator

Santiago Barcón, Ignacio Suárez, and Luis Flamenco

Abstract—The present work shows a real case of an industrial plant in México and the solution of problems in the electric system caused by the damage of a static var compensator. With help of a power system simulation we could evaluate several alternatives of solution and determine which is better from the technical and economic point of view to be applied. The objective was to improve the conditions of electric system through a low cost solution and quick application.

Index terms--
- Electric variables measurement.
- Harmonic distortion.
- Power system simulation.
- Static var compensator.
- Simulation software.

I. INTRODUCTION

In Mexico there are only two utilities, both companies are property of the government. Since November 1991 they had a policy of penalizing to the users with a lower power factor than 0.90 and the users with a PF upper than 0.90 they received a rebate up to 2.5% in their monthly electrical billing. At this time there are not a penalizing for high harmonic distortion on the PCC, however in a few years is too possible will exist a regulation to this respect.

With the damage of a static var compensator of a steel mill in Mexico, several problems arise in the electric system: low power factor less than the utility recommendations on PCC, poor voltage regulation, damage at the electronic equipment and the high probabilities of harmonic resonance that meant a risk condition to the plant.

Due the time to deliver a new static var compensator, the company decided to look for other solutions to improve the conditions of electric system, with the purpose of not altering the normal production. The alternative of improvement should be of low cost and quick application.

The plant has two productive areas: lamination and steel mill in the last there are two electric arc furnaces (the shaft and the EBT). In the figure 1, is included an one line diagram simplified.

The most affected area for the loss of static var compensator was the lamination, because here is located the mayor quantity of the electronic equipments, so all the efforts had to be focused to solve the problems in the lamination bus.

The lamination plant is constituted by two transformers of 30 MVA working with the close link in 13.2 kV, from this bus are fed 11 circuits that supply to several loads in which are included: DC motor drives, AC motor drives, induction motors, illumination and two capacitors banks.

There are two conditions to operation of lamination plant: normal load (20.13 MW with a PF of 0.904) and low load (11.04 MW with a PP of 0.996).

II. METHODOLOGY

In order to determine the solution of electric system it was necessary:
A. To carry out electric variables measurement for each one of conditions of plant.
B. To confirm the name plates data of the equipments in the electric system.
C. Modeling the electric system in the simulation software.
D. To obtain and evaluated the solution under the several conditions.
E. Final results.
A. Electric variables measurement.

Electric variables measurement were carried out at each one of feeders of plant with three power quality analyzers, with the purpose to detect the feeders with the major harmonic distortion and mainly to determine the behavior of load for each one of the operation conditions.

In the next table the measurement summary is shown, and is included a evaluation of IEEE 519-92 [1]-[2] for current:

<table>
<thead>
<tr>
<th>Feeder</th>
<th>kW</th>
<th>PF</th>
<th>I_THD (%)</th>
<th>IEEE 519-92</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR1-2</td>
<td>700</td>
<td>0.960</td>
<td>15.50</td>
<td>Outside</td>
</tr>
<tr>
<td>GR1-4</td>
<td>480</td>
<td>0.800</td>
<td>4.90</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-5</td>
<td>10,799</td>
<td>0.733</td>
<td>4.30</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-8</td>
<td>550</td>
<td>0.960</td>
<td>31.00</td>
<td>Outside</td>
</tr>
<tr>
<td>GR1-9</td>
<td>250</td>
<td>0.800</td>
<td>4.20</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-11</td>
<td>860</td>
<td>0.733</td>
<td>2.10</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-12</td>
<td>1,739</td>
<td>0.770</td>
<td>3.60</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-14</td>
<td>2,500</td>
<td>0.660</td>
<td>22.30</td>
<td>Outside</td>
</tr>
<tr>
<td>GR1-15</td>
<td>1,294</td>
<td>0.610</td>
<td>3.60</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-16</td>
<td>641</td>
<td>0.730</td>
<td>0.80</td>
<td>Inside</td>
</tr>
<tr>
<td>GR1-17</td>
<td>273</td>
<td>0.74</td>
<td>0.80</td>
<td>Inside</td>
</tr>
</tbody>
</table>

Table 1. Summary of electrical variables measurement.

At 13.2 kV bus are connected a capacitor bank of 9600 kVAR to 16.64 kV, while in the circuit GR1-8 exist another capacitor bank of 600 kVAR to 16.64 kV, so in this feeder the I_THD is high.

Next are shown the signal and harmonics for current of the GR1-14 feeder.

![Event waveform/detail](image)

Total RMS: 114.27 Amps
DC Level: 10.15 Amps
Fundamental (H1) RMS: 111.05 Amps
Total Harmonic Distortion (H02-H50): 22.37% of FND
Even contribution (H02-H50): 0.27% of FND
Odd contribution (H03-H49): 22.37% of FND

In these graphs can be observed how the fifth harmonic is outside of the recommendations and also we have seventh and eleventh with important values.

On the other hand, the V_THD at 13.2 kV bus is normally inside of the recommendation the value oscillate between 1.6% to 2.9%, depending if the EBT turned on or turned off.

In general could mentioned that in the secondary of transformers T1 y T2 of lamination plant is fulfilled the recommendations of the IEEE 519-92.

B. To confirm the name plates data of the equipments in the electric system.

This section consisted in to verify the name plates data of equipments that were considered in the study, from transformers until cables size and longitude of lamination plant.

C. Modeling the electric system in the simulation software.

With the electric measurements and the information of system was proceeded to modeling the loads, the transformers, the cables, etc. in the simulation software.

D. To obtain and evaluated the solution under the several conditions.

Once modeling the electric system, it was carry out simulations that includes from the original situation until to obtain the alternative solution.

Next are shown some of the results obtained in the simulation software for the original condition, with the two capacitors banks and EBT furnace operating. This condition was for the normal load at lamination plant.

![Original condition one line diagram results](image)

The results for the original condition can be summarized in:

1. The total power factor of the plant was 0.904, this value is on the limit of power supply recommendations.
2. The voltage at 13.2 kV bus, was 96.1% to the nominal voltage.
3. The V_THD at 13.2 kV bus, was 2.9% this value meet the IEEE 519-92 recommendations. The most important harmonics were the 7th and the 11th with 2.3% and 1.3% respectively of the fundamental voltage.
4. The capacitors banks show high THD of current, however because they are designed to 130% up to the nominal voltage do not present problems.

In the figure 4, are shown the signal and harmonics for voltage at 13.2 kV bus.
In so far as, the figure 5 is shown the impedance of system vs frequency at 13.2 kV bus.

In the last curve can be observed the parallel resonance at 8th harmonic and is important to mention that this represent a risk condition for the plant, because is near to the 7th harmonic.

The signal and harmonics for current of capacitor bank 9600 kVAR are shown in the next graph.

In these graph could be observed that the most important harmonics are the 7th, 11th and the 13th with 16.2%, 14.6% and 8.9% respectively of the fundamental current.

Applying the same procedure of analysis, several conditions of electric system were studied, in the next table are show the summary of results.

<table>
<thead>
<tr>
<th>Original Situation</th>
<th>kW</th>
<th>PF</th>
<th>kV</th>
<th>(%Vnom)</th>
<th>V_THD (%)</th>
<th>I_THD(%)</th>
<th>Cap. Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>20129</td>
<td>0.904</td>
<td>12.679</td>
<td>96.05</td>
<td>2.00</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td>20,122</td>
<td>0.921</td>
<td>13.513</td>
<td>102.37</td>
<td>2.50</td>
<td>21.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Summary results for original condition.

The sign (+) indicates that the power factor is capacitive.

In the last table can be observed when the capacitors banks are off the harmonics go down, but affect the power factor and the voltage regulation, on the other hand when the capacitors banks turned on the power factor is improved and also the voltage at 13.2 kV bus is better, however the harmonics goes up and exist a risk condition due possible harmonic resonance near to 7th (cases 1, 2 y 4).

After studying several solutions alternatives, was concluded that the present the more advantages due low cost and quick application consisted:

1. Rehabilitate and install the detuned filter of 12 MVAR to 16.64 kV at 13.2 kV bus, this filter was off operation.
2. To disconnect both capacitors banks of 9600 kVAR and the 600 kVAR.
3. Change the actual tap position of transformers T1 and T2, to increase the voltage at secondary in 2.5%.

The detuned filter was used in the past, to improved the total power factor of plant before the construction of EBT furnace and their harmonic filters, after when this area was turned on the detuned filter was disconnect and some of their components were used in other sections.

The results obtained in the simulation software after the application of the recommendations are show in the next one line diagram.
The results of future condition can be summarized in:

1. The power factor of the plant was 0.935, this value fulfill with the power supply recommendations.
2. The voltage at 13.2 kV bus, was 98.13% at nominal voltage.
3. The V_THD at 13.2 kV bus, was 1.6% this value fulfill the IEEE 519-92 recommendations. The most important harmonics were the 11th and the 13th with 1.02% and 0.09% respectively of the fundamental voltage.
4. The detuned filter show a low THD of current 3.2%.

In the next figure, are shown the signal and harmonics for voltage at 13.2 kV bus.

In the figure 9, are shown the impedance of system vs frequency at 13.2 kV bus.

In the last curve can be observed like near of 4th harmonic the impedance of system was reduce due the operation of detuned filter and later the trend is directly proportional to the frequency.

The signal and harmonics for current of detuned filter are shown in the figure 10.

In these graph can be observed that the most important harmonics are the 5th, 11th and 13th with 1.93%, 1.81% and 1.35% respectively of the fundamental current.
III. CONCLUSIONS.

The present work illustrate one of the multiples applications of power system simulator to solve real problems at industrial plants.

Is important to remember that the possible solutions of power system was selected the alternative of low cost and the quick application, just a temporal solution.

Finally, in this specific case was analyzed like an application of detuned filter could be a very good solution to power quality problems, such voltage regulation and harmonic reduction.

IV. REFERENCES.


Santiago Barcón was born in Mexico City in 1957. He is electrical engineer from the Universidad Iberoamericana, he received the master degree in BA from Instituto Tecnológico de Estudios Superiores de Monterrey. He has worked in several companies attending from electrical maintenance areas up to sales and production management, among them Vitro and ABB. Presently, he is partner and president of Inelap,* S.A. de C.V. manufacturer low and high voltage capacitor for power factor correction, harmonic filters and protection panels. Inelap is an ISO 9001 facility. His research interests include capacitor banks, harmonics and power quality. He participated in the Power Quality 93, 95 and 97 and many conferences in Mexico and Central and South America. He is member of IEEE.

Ignacio Suárez was born in México City. He is electrical engineer from Universidad Nacional Autónoma de Mexico, his experience is more than 15 year in the electric area, he has worked in many different companies where he has participated in design engineering, equipment installation, training, planning, commercial and administrative functions. At the moment he is engineering manager in Inelap,* S.A. de C.V., where his participation it obtained the ISO-9001 certification. He has participated in many conferences in Mexico, in 2000 he was speaker in the Power System World in USA.

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*Arteche acquired Inelap in 2005